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NICKEL-ZINC BATTERIES FOR RPV APPLICATIONS

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JUNE 1981

INTERIM TECHNICAL REPORT FOR PERIOD 15 DECEMBER 1979 - 15 NOVEMBER 1980

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This technical report has been reviewed and is approved for publication.

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: AFWAL-TR-81-2039	2. GOVT ACCESSION NO.: AD-A111051
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): NICKEL-ZINC BATTERIES FOR RPV APPLICATIONS	5. TYPE OF REPORT & PERIOD COVERED: Iterim Technical Report 15 Dec. 79 thru 15 Nov.80
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Donna Dappert	8. CONTRACT OR GRANT NUMBER(s): F33615-78-C-2058
9. PERFORMING ORGANIZATION NAME AND ADDRESS: EAGLE-PICHER INDUSTRIES, INC. P.O. Box 47 Joplin, Missouri 64801	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62203F
11. CONTROLLING OFFICE NAME AND ADDRESS: Aero Propulsion Laboratory (AFWAL/POOC-1) Air Force Wright Aeronautical Laboratories Wright-Patterson AFB Ohio 45433	12. REPORT DATE: June 1981
	13. NUMBER OF PAGES: 62
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report)
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE: N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Batteries, Nickel-Zinc, RPV Applications

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Interim results are presented for a program dealing with the placement of nickel-zinc batteries in specific military applications, namely the BQM-34A and the PQM-102 Remotely Piloted Vehicles. The nickel-zinc system was chosen for these applications because RPV's demand a high quality secondary battery that offers a compromise between long life (calendar and cycle) and low weight and volume. Program tasks include continued development of the nickel zinc system, calendar and cycle life testing of the two candidate batteries, qualification

testing, and flight testing in operational RPV's. Test results of developmental cells and batteries include cycle life testing of various separator materials, high rate/low temperature discharges with various types of nickel electrodes, zinc electrode substrate, and charging methods. Calendar and cycle life testing is underway which will demonstrate the ability of the nickel-zinc system to be routinely cycled over an extended period of time.

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MAR-5013

1.0 INTRODUCTION

The objective of this portion of the program is to develop the technology necessary for long-life, low cost, rechargeable nickel-zinc batteries as a replacement for existing lead acid batteries used in BQM-34A remotely piloted vehicles. The nickel-zinc batteries herein described (Eagle-Picher Part No. MAR-5013) are to be physically and electrically interchangeable with existing lead acid batteries. The general technical requirements for the nickel-zinc battery are:

1) Battery voltage shall be compatible to the vehicle electrical system. (28 V. nominal)
2) Battery charging requirements shall be compatible to existing ground charging equipment.
3) Battery weight shall not exceed 30 pounds.
4) Battery capacity shall be greater than 20 ampere-hours.
5) Battery calendar life shall exceed 3 years with a projected design goal of 5 years.
6) Battery cycle life shall exceed 120 cycles with a projected design goal of 200 cycles.

Primary advantages for the selection of the nickel-zinc battery system as a replacement for the existing lead acid batteries used in the BQM-34A target drones are:

1) The secondary nickel-zinc system is able to provide superior Amp-Hr capacity with respect to volume as compared to the existing lead acid battery system. Only marginal capacity has

1.0 INTRODUCTION (continued)

been obtained from the existing lead acid batteries due to vehicle volume and weight limitations. Nickel-zinc systems are able to incorporate a higher energy in the limited vehicle volume and weight restrictions.

2) The nickel-zinc battery is capable of providing better high rate performance while maintaining a high energy package. Specifically, the nickel-zinc battery is capable of delivering greater than 12.5 AH at the 45 Amp discharge rate.
3) The nickel-zinc battery will offer better cycle life under the high rate discharge conditions.

2.0 DEVELOPMENT & EVALUATION

Development and Evaluation testing during this reporting period was a continuation of investigations conducted during the first interim period. These investigations, conducted during this reporting period, have dealt with separator/electrode optimization, nickel electrode manufacture, mechanical components, charging methods, and battery design.

Data at this point, has been generated from three series of development test cells.

2.1 Development & Evaluation-First Series of Test Cells

The first series of test cells for the Development & Evaluation Task was previously described during the first interim reporting period (Ref AFWAL-TR-80-2050).

2.2 Development & Evaluation-Second Series Test Cells

The second series of test cells for the Development Evaluation Task is described in Table 1.

TABLE 1

SECOND SERIES OF DEVELOPMENT TEST CELLS

CELL NUMBER	SEPARATOR	KOH	NEGATIVE ELECTRODE
13,14	2	31%	Standard
15,16	3	31%	Standard
17,18	4	31%	Standard
19,20	3 * Buffered	31%	Standard
21,22	4 * Buffered	31%	Standard
23,24	1	31%	Standard
25,26	5	31%	CdO Additive
27,28	5	31%	Zn & ZnO Mixture

*Buffered with Borate

TABLE 1 (continued)

SECOND SERIES OF DEVELOPMENT TEST CELLS

Separator Systems

1. +, pellon, 3400 Celgard, cellophane, 3400 Celgard, cellophane, pellon, -
2. +, pellon, 3400 Celgard, cellophane, 3400 Celgard, pellon, -
3. +, pellon, 4 layers 3400 Celgard, pellon, -
4. +, pellon, 3400 Celgard, 2 layers Ni coated Celgard, 3400 Celgard, pellon, -
5. +, pellon, 3501 Celgard, cellophane, 3501 Celgard, cellophane, pellon, -

Test Methods (Automatic Cycle System)

Cycle Test - 12.5 Amp discharge for one (1) hour and fifteen (15) minutes followed by a five (5) hour constant potential charge at 1.90 volts/cell with the current limited to 5 Amps.

Cell characteristics for the Second Series of Development Cells are described in Table 2.

TABLE 2

SECOND SERIES CELL DESIGN

STANDARD FEATURES

Cell Case-Eagle-Picher Standard 20 AH

Number of Electrodes - 12 Positive/13 Negative

Electrode Area - 7.48 in^2

Current Density - .07 A/in^2

Positive Theoretical Capacity - 21 AH

Negative Active Material Loading - 1.32 gm/in^2

Cell numbers 17, 18, 21, & 22 were not constructed. At the time of the Second Series construction, the nickel coated celgard material was not available. Sample procurements of nickel coated separator materials were obtained from RAI Research Corporation. These samples were incorporated into cells constructed for the Third Series. (Refer to section 2.3 for the Third Series narrative).

2.2.1 Second Series Test Objectives

The test objectives for this group of cells were:

1) Evaluate cell life for each of the various separator systems.
2) Determine the effect of buffered electrolyte on cell calendar life. In theory, buffered electrolyte reduces the soluability of zinc in the electrolyte and delays the process of zinc dendritic growth.
3) Compare the effect of various negative electrode additives on cycle life. The CdO additive, in theory, should improve cycle life, reduce shape changes in the negative electrodes, and reduce the gasing of the negative electrode.

2.2.2 Technical Results & Discussion

The cells were formed and received a 12.5 Amp. discharge. The cells were then cycle tested as described in Section 2.2. Charge performance and Amp Hr. capacity was essentially the same, regardless of separator variances, electrolyte variances, and negative electrode differences.

2.2.2 Technical Results & Discussion (continued)

The cells have completed the following number of cycles at the conclusion of this reporting period. The completed cycles are listed in Table 3.

The discharge time (12.5 Amp discharge) has been adjusted to account for reduced cell capacity. Refer to Figure 1.

TABLE 3.

SECOND SERIES - CYCLE STATUS

CELL NUMBER	CYCLES COMPLETED
13	425 (testing suspended)
14	425 (testing suspended)
15	425 (shorted, cell reversed)
16	344 (testing suspended)
17	Not constructed
18	Not constructed
19	327 (mechanical failure -terminal)
20	344 (testing suspended)
21	Not constructed
22	Not constructed
23	29 (mechanical origin)
24	43 (short across cell pack)
25	344 (testing suspended)
26	344 (testing suspended)
27	43 (short across cell pack)
28	325 (failure not located-cell reversed)

SECOND SERIES TEST CELLS
DEPTH OF DISCHARGE

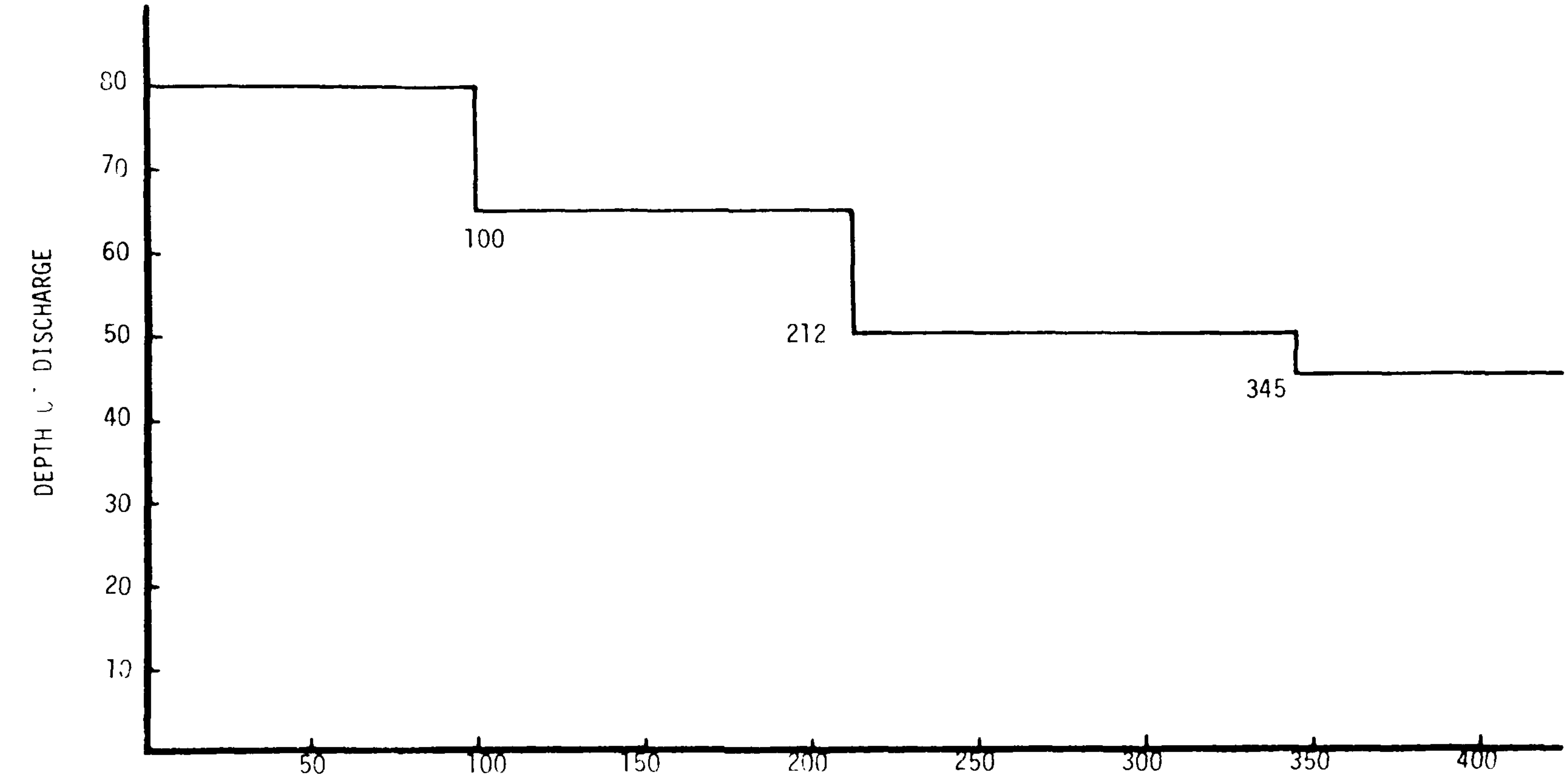


FIGURE 1

2.2.3 Cycle Status

At the conclusion of the first interim reporting period, only cell numbers 13, 14, & 15 remained in the test configuration. End of testing results for cells other than 13, 14, & 15 are summarized in the first interim report (AFWAL-TR-80-2050). End of discharge cell voltage data, randomly selected throughout the Second Series Testing duration, is presented in Table 4. Voltage reversal of cell number 28 was previously covered in the first interim reporting period.

During this reporting period, testing was suspended during discharge number 425 on cells # 13, 14, and 15. At this time, cell # 15 shorted. Cell # 15 began voltage reversal on discharge number 424. Discharge 424 for cell numbers 13, 14, and 15 is shown in Figure 2. Postmortum examination of cell # 15 revealed several low grade shorts throughout the entire cell pack. The low grade shorts resulted from zinc dendritic penetration through the four layers of Celgard 3400

Continued testing of cells # 13, # 14, and 15 beyond 50% of the original rated capacity was to generate additional separator data rather than capacity data. These cells had demonstrated more than enough cycles for RPV applications at the suspension of testing.

TABLE 4

END-OF-DISCHARGE VOLTAGES
12.5 A Rate Discharge

CYCLE No.	AH Removed	13	14	15	16	19	20	23	24	25	26	27	28
1 (Formation)	20.8	1.63	1.61	1.62	1.63	1.62	1.62	0.23	0.23	1.61	0.23	1.60	1.57
15	15.6	1.61	1.59	1.61	1.61	1.60	1.60	0.24	1.57	1.59	1.54	1.58	1.57
25	15.6	1.59	1.57	1.58	1.58	1.58	1.58	0.21	1.46	1.56	0.16	1.55	1.53
33	15.6	1.58	1.57	1.58	1.58	1.58	1.58	Shorted Cycle # 30	1.42	1.56	1.40	1.57	1.55
43	15.6	1.58	1.56	1.57	1.58	1.57	1.57		0.22	1.53	0.22	0.22	0.22
67	15.6	1.55	1.52	1.55	1.55	1.54	1.54		Shorted Cycle 43	1.51	0.20	Shorted Cycle #43	0.20
95	15.6	0.22	1.54	1.53	1.54	1.52	1.51			1.32	0.19		0.17
108	12.5	1.60	0.21	1.59	1.59	1.58	1.58			1.57	1.55		1.53
127	12.5	1.60	1.59	1.59	1.59	1.57	1.57			1.59	1.56		1.51
139	12.5	1.57	1.55	1.55	1.56	1.54	1.54			1.56	1.39		0.98
146	12.5	1.55	1.51	1.52	1.53	1.50	1.51			1.54	0.20		0.19
153	12.5	1.56	1.56	1.53	1.53	1.51	1.51			1.55	0.23		0.21
163	12.5	1.53	1.43	1.48	1.49	1.45	1.47			1.53	0.19		0.19
189	12.5	1.51	0.19	1.34	1.44	1.32	1.38			1.51	0.19		0.19
195	12.5	1.51	0.21	1.14	1.40	1.23	1.33			1.49	0.19		0.19
200	12.5	1.51	0.22	1.09	1.41	1.31	1.37			1.51	0.19		0.18
216	9.4	1.60	1.59	1.58	1.59	1.56	1.57			1.59	1.58		1.54
225	9.4	1.62	1.60	1.60	1.60	1.58	1.58			1.61	1.60		1.56
230	9.4	1.57	1.52	1.53	1.53	1.50	1.53			1.56	1.48		0.23
244	9.4	1.54	1.48	1.42	1.46	1.37	1.47			1.54	1.25		0.16
259	9.4	1.53	1.46	1.20	1.36	1.25	1.46			1.52	0.78		0.08

TABLE 4

END OF DISCHARGE VOLTAGES
(continued)

CYCLE No.	AH Removed	13	14	15	16	19	20	23	24	25	26	27	28
263	9.4	1.53	1.44	1.07	1.25	1.25	1.45			1.51	0.18		-0.09
276	9.4	1.53	1.44	1.00	1.27	1.31	1.47			1.53	0.28		-0.30
281	9.4	1.52	1.32	0.82	0.91	1.34	1.47			1.51	0.17		-0.52
296	9.4	1.50	0.71	0.57	0.69	1.08	1.38			1.48	0.19		-0.95
318	9.4	1.51	0.29	0.47	0.62	1.10	1.40			1.49	0.20		-1.96
325	6.3	1.59	1.58	1.41	1.52	1.39	1.56			1.59	1.58		-2.16
* Discharge Discontinued												* Cell vented	
329	9.4	1.55	1.40	1.35	1.39	Shorted Cycle # 327	1.51			1.55	1.22		
339	9.4	1.51	0.28	0.66	0.62		1.37			1.52	0.21		
344	9.4	1.45	0.17	0.17	0.25		1.16			1.45	0.16		
345	7.5	1.61	1.60	1.59									
351	7.5	1.56	1.53	1.53									
364	7.5	1.53	1.45	1.14									
369	7.5	1.51	1.38	0.61									
385	7.5	1.48	0.18	0.33									
397	7.5	1.48	0.18	0.30									
421	7.5	1.42	0.18	0.16									
424	7.5	1.38	0.12	-0.11									
425	5.7			* 1.05									

*Discharge Discontinued
Cell #15 Hot

SECOND SERIES TEST CELLS
DISCHARGE 424

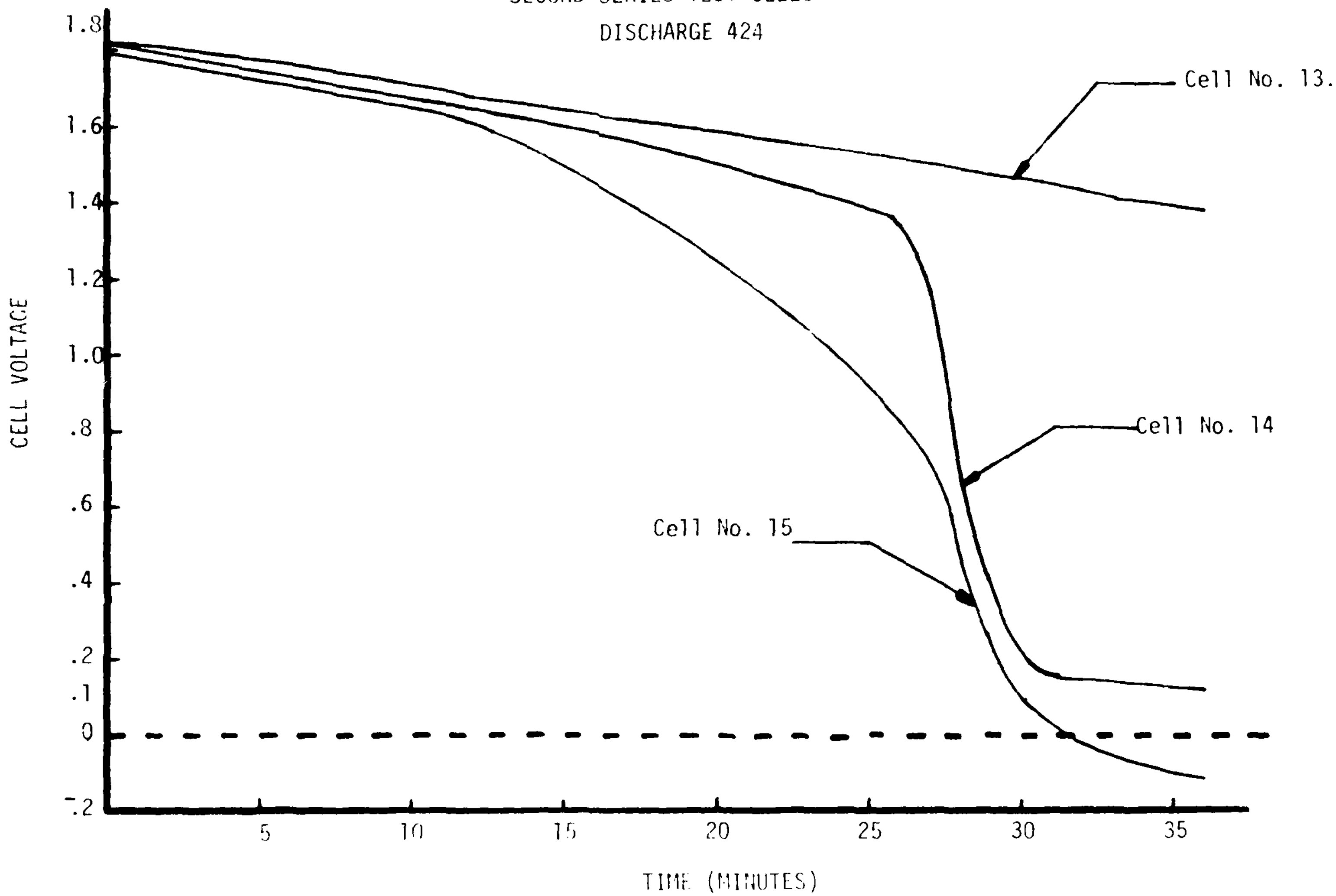


FIGURE 2

2.2.4 Second Series Final Results

Final results for the Second Series test cells are summarized as follows:

2.2.4.1 Separator Systems

In general, all the separator systems tested in the Second Series achieved adequate cycles for RPV applications with the exception of separator system 1. Cells (23 & 24) containing system 1 (2 Celgard/ 2 Pudo) did not generate a sufficient amount of cycles to produce results applicable to cell life in comparison with separation; however, results obtained from cells in the First Series Test Cells with this separator system demonstrated adequate cycles for RPV applications.

2.2.4.2 Buffered Electrolyte

The addition of buffered electrolyte to cells No. 19 and 20 did not significantly improve cell cycle life when compared to Cells No. 15 & 16 which contained the same separator as cells No. 19 & 20. Data did not indicate these cells ran significantly better than other cells in the Second Series.

2.2.4.3 Negative Electrode Additives

Cells containing the CdO additive (cells no. 25 & 26) did not cycle significantly better than cells containing standard EP negative electrodes.

Data generated on cells containing a Zn and ZnO mixture (cells no. 27 28) indicated these cells did not cycle as well as other cells in the test configuration. Cell #27 shorted early in cycle life due to a short across the cell pack. Cell capacity in cell #28 began fading early in cycle life for this cell.

2.3 Development & Evaluation -Third Series Test Cells

The third series of test cells for the Development and Evaluation Task is described in Table 5 on the following page.

TABLE 5

THIRD SERIES OF DEVELOPMENT TEST CELLS

CELL NUMBER	TEST VARIABLE	
29	*1128-196-1 HDPE/MA	+ pellon, 3400 celgard RAI,3400 cellgard, pellon,-
30	*1128-196-2-P6001	
31	*1128-196-3 LT-10	
32	*1128-196-4 P700 40/10	
33	*1128-200-5 Dexter Paper	
	*RAI Ni coated separators	
34,35,36,37	+, pellon, 3400 celgard, 3400 celgard, 3400 celgard, 3400 celgard, pellon,-	
38,39,40 (control for cells 29-33)	+, pellon, 3400 celgard, 3400 celgard pellon ,-	
41,42,43	+ pellon, 3400 celgard, cellophane 3400 celgard, pellon,-	
47,48,49 50,51, 52,	Copper grid-negative	+,pellon, 3400 celgard, cellophane 3400 celgard, cellophane, 3400 celgard, cellophane pellon,-

Test Methods (Automatic Cycle System)

Cycle Test- Six (6) hour constant potential charge at 1.91 volts/cell with the current limited to five (5) amps followed by a ten (10) amp discharge for two (2) hours. Cell characteristics for the Third Series of Development cells are described in Table 6 on the following page.

TABLE 6.

THIRD SERIES CELL DESIGN
STANDARD FEATURES

Cell Case - MAR-5013 (modified)

Number of Electrodes - 8 Positives/7 Neg

Electrode Area - 7.48 in^2

Current Density - (10 Amp Discharge) = .10 $Amps/in^2$

Positive Theoretical Capacity = 24 AH

Negative Active Material Loading = 1.9 gm/in^2

All cells contain conventionally impregnated nickel electrodes. The cells were constructed in the MAR-5013 cell case. The transparent MAR-5013 cell case made electrolyte level maintenance much easier for the Third Series Cells compared to the First and Second Series cells constructed in opaque ABS cell cases.

2.3.1 Third Series Test Objectives

The objectives for this group of cells were:

1) Evaluate RAI nickel coated separator for effectiveness in zinc dendrite stoppage.

2) Evaluate cell cycle life for cell numbers 34-37. The separator system (4 layers celgard 3400) is not degradable in the presence of electrolyte.

3) Evaluate the use of copper grid and copper tabs in the negative electrode instead of the silver grid and silver tabs previously utilized in the negative electrodes. Escalating prices of silver have made it very desirable to completely remove silver from the nickel-zinc system.

2.3.2 Technical Results and Discussion

The cells were formed at a 3 amp constant current rate. Cells Nos. 29-33 were discharged at a 12 amps constant current until the first cell in the series reached a cut-off voltage of 1.35 volts. Cell nos. 34-43, and 47-52 were discharged at 14 amps constant current until the first cell in each group reached a cut-off voltage of 1.35 volts. The different rates of discharges (12 amps vs. 14 amps) occurred because of the use of different cyclers in the automatic cycler system. Table 7 shows the amp hour capacity obtained from each variable group. See Table 7 on the following page.

TABLE 7

THIRD SERIES FORMATION DISCHARGE CAPACITIES

CELL GROUP NUMBER	RATE OF DISCHARGE	AMP HOUR CAPACITY
29-33	12	29
34-43	14	28
47-52	14	28

The cells have completed the following number of cycles at the conclusion of this reporting period. Cycle status for the cells are summarized in Table 8. End-of-discharge cell voltage data, randomly selected, is listed in Table 9 for the Third Series cells.

TABLE 8

THIRD SERIES TEST CELLS

CELL NUMBER	CYCLES COMPLETED
29-33	30 (testing suspended)
34-37	69 (testing suspended)
38-40	114(testing in progress)
47-52	114(testing in progress

2.3.3 Cycle Status

Cell performance for the first twenty (20) cycles was essentially the same, however, during cycle 20, some differences in individual cell charge characteristics became evident. Cells # 29-33 began reaching high end-of-charge voltages. End-of-charge voltages and end-of-discharge voltages for cycle number 25 are summarized in Table 10 on the following page.

TABLE 9

END OF DISCHARGE VOLTAGES

10 AMP RATE OF DISCHARGE

		CELL													NUMBERS						
CYCLE NUMBER	DEPTH of DISCHARGE	29	30	31	33	34	35	36	37	38	39	40	41	42	43	47	48	49	50	51	52
2	100%	1.60	1.61	1.61	1.60	1.57	1.60	1.60	1.60	1.60	1.60	1.57	1.60	1.60	1.59	1.59	1.58	1.59	1.58	1.59	1.58
8	100%	1.56	1.57	1.57	1.56	1.50	1.56	1.56	1.56	1.57	1.57	1.53	1.58	1.58	1.57	1.57	1.55	1.57	1.55	1.57	1.55
13	100%	1.55	1.55	1.55	1.55	1.49	1.55	1.54	1.54	1.55	1.56	1.52	1.58	1.58	1.58	1.57	1.56	1.57	1.56	1.58	1.57
25	100%	1.50	1.51	1.52	1.52	1.14	1.52	1.51	1.52	1.51	1.53	1.40	1.52	1.52	1.52	1.52	1.47	1.51	1.48	1.52	1.51
27	100%	1.48	1.51	1.52	1.53	1.18	1.51	1.52	1.52	1.52	1.53	1.45	1.52	1.53	1.52	1.52	1.44	1.51	1.48	1.51	1.52
31	100%	Testing Discontinued				1.51	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.51	1.55	1.55	1.55	1.55
40	100%					1.06	1.43	1.23	1.44	1.45	1.43	0.69	1.48	1.48	1.48	1.48	1.08	1.46	1.39	1.48	1.40
52	100%					1.10	1.51	1.46	1.51	1.51	1.52	1.08	1.50	1.49	1.46	1.52	0.64	1.51	1.45	1.52	1.42
57	90%					1.07	1.48	1.30	1.48	1.48	1.47	0.98	1.52	1.52	1.50	1.52	1.32	1.52	1.51	1.51	1.50
61	63%					1.45	1.54	1.52	1.54	1.54	1.54	1.48	1.56	1.56	1.56	1.56	1.45	1.56	1.56	1.56	1.55
65	63%					1.36	1.52	1.49	1.52	1.52	1.51	1.36	1.55	1.54	1.53	1.55	1.42	1.55	1.53	1.55	1.54
76	63%					1.28	1.51	1.44	1.51	Testing Discontinued Charge #69						1.52	1.22	1.52	1.50	1.53	1.51
87	63%					1.06	1.43	1.04	1.45							1.49	0.97	1.49	1.47	1.50	1.48
91	63%					0.94	1.35	0.36	1.41							1.48	0.95	1.47	1.44	1.49	1.47
96	63%					0.99	1.32	0.28	1.40							1.51	1.08	1.51	1.49	1.52	1.50
100	63%					0.42	0.92	0.22	1.22							1.48	1.04	1.49	1.47	1.48	1.47
105	63%					0.19	0.42	0.17	0.55							1.45	0.81	1.44	1.39	1.47	1.42
110	63%					0.31	0.58	0.18	0.95							1.47	0.82	1.45	1.42	1.47	1.44
114	63%					0.87	0.80	0.34	1.25							1.36	1.25	1.35	1.38	1.42	1.34

TABLE 10

THIRD SERIES - CYCLE 25

Cell No.	End of Charge Voltage	End of Discharge Voltage
29	1.96	1.50
30	1.92	1.51
31	1.97	1.52
32	1.93	1.51
33	1.92	1.52
34	1.89	1.14
35	1.91	1.52
36	1.91	1.51.
37	1.89	1.52
38	1.88	1.51
39	1.90	1.53
40	1.89	1.40
41	1.95	1.52
42	1.95	1.52
43	1.93	1.52
47	1.88	1.52
48	1.88	1.47
49	1.88	1.51
50	1.88	1.48
51	1.88	1.52
52	1.88	1.51

Due to equipment limitations all cells in the Third Series were series connected and cycled off the same automatic cycle equipment. Cycle #25 data indicated not all cells were fully charged at the end of charge #25, due to the high voltages obtained in cells 29-33 which limited the charge current. Variances in charging characteristics were attributed to separator variables which subsequently affected internal cell resistance and charging characteristics.

High end-of-charge voltages for cell numbers 29-33 were not consistent to any particular cell. High voltages varied from cycle-to-cycle in which cell would exhibit the high end-of charge voltage.

Testing was interrupted during the 29th cycle in order to regroup the cells for continued testing purposes. A conditioning cycle was placed on each cell group. This cycle consisted of charging the cells by cell variable group until they were fully charged,and individually discharging each cell to a cutoff voltage of 1.35 volts. Once the conditioning cycle was concluded, the cells were placed back on the automatic cycle system for charge #30. Two hours and twenty-five minutes into charge, testing was suspended because the cells were exhibiting premature high voltages.

2.3.4 Continued Testing

Further testing of the cells was done by variable groups. Regrouping of the cells is described as follows:

Cells 29-33: Testing was suspended due to limited equipment availability. Data, at the suspension of testing did not indicate cell performance for this group of cells was significantly improved over other cells in the Third Series. In fact, these cells were difficult to charge because of premature high voltage.

Cells 34-37, 38-40, 41-43: The cells were cycled as a battery on the automatic cycle test equipment since these cells ran compatible with each other.

2.3.4 Continued Testing (continued)

Cells 47-52: The cells were cycled as a battery on separate cycle equipment. The primary reason for testing this group of cells is to determine if copper grid and copper tab material can successfully be utilized as a replacement for silver grid and silver tabs in the negative electrodes.

Testing was suspended on cells # 38-40 and #41-43 during cycle #69. At this time, it was becoming difficult to charge cells #34-43 as a battery. It was more desirable to continue testing cells #34-37 because this separator system is not degradable in the presence of electrolyte.

As indicated in Table 8, the cells have completed 114 cycles. End of discharge cell voltages for cells 34-37 are all below 135 volts. Continued testing of cells 34-37. and 47-52 will be conducted at a 50% DOD.

Figure 3 represents the DOD regime for the Third Series **Cells.**

3.0 MAR-5013 BATTERY DESIGN

The potential nickel-zinc battery to be used in the place of existing lead-acid batteries has been assigned Eagle-Picher battery number MAR-5013. General characteristics of this battery are listed in Table 11.

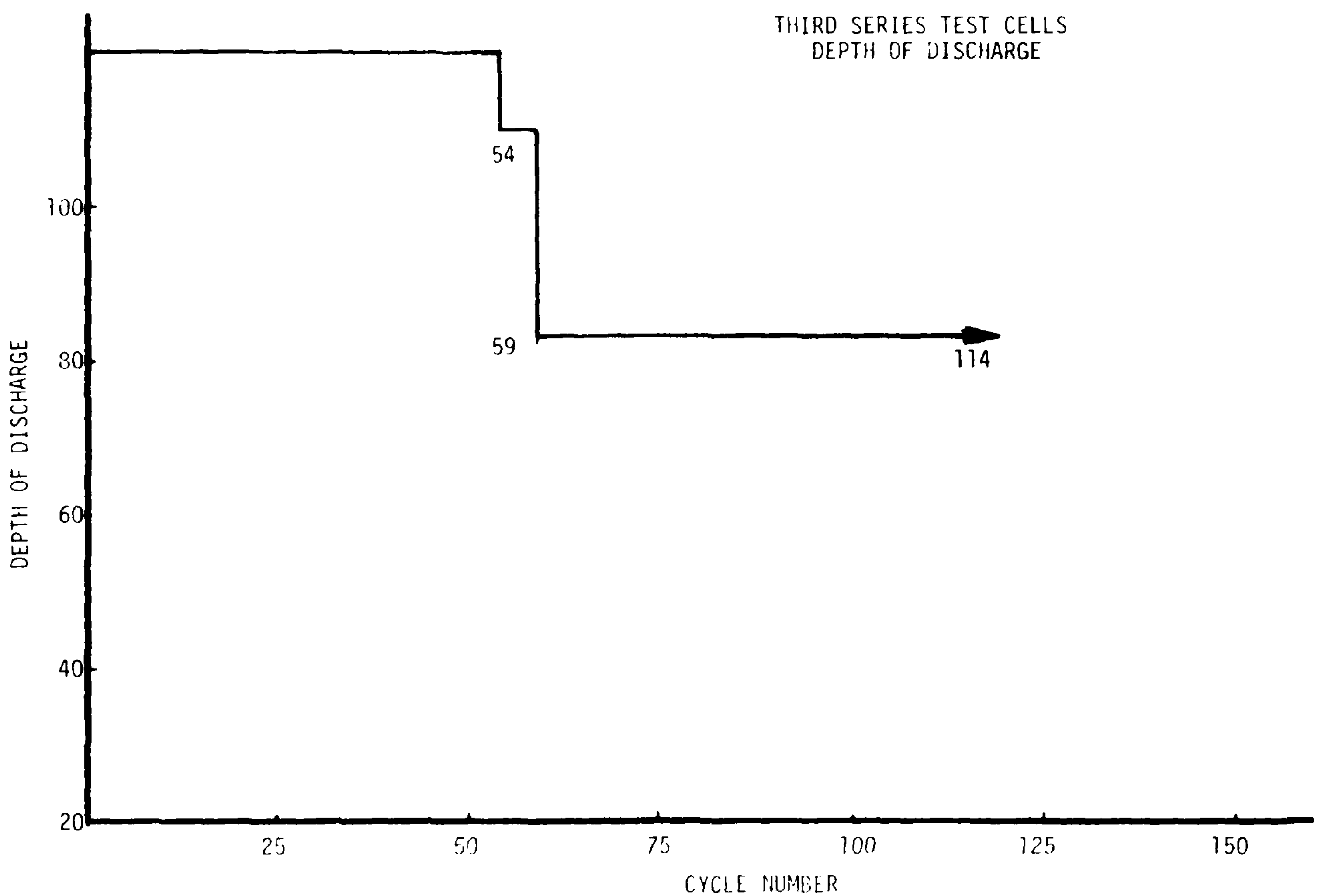

THIRD SERIES TEST CELLS
DEPTH OF DISCHARGE
DEPTH OF DISCHARGE
100
80
60
40
20
54
59
114
25
50
75
100
125
150
CYCLE NUMBER

Figure 3

TABLE 11.

MAR-5013 BATTERY DESIGN

NUMBER OF CELLS:	18
BATTERY WEIGHT:	27 lbs. (including container)
SIZE:	6.40" X 4.75" X 11.75"
NOMINAL VOLTAGE:	28 Volts
MIDPOINT VOLTAGE AT 15.0 Amps:	28.5 V - Pickett 29.0 V - Conventional
MIDPOINT VOLTAGE AT 45.0 Amps:	26.0 V - Pickett 27.0 V - Conventional
OPEN CIRCUIT VOLTAGE, CHARGED:	32 V - 33.5 V
OPEN CIRCUIT VOLTAGE DISCHARGED:	29.5 V - 31 V
CELL CASE MATERIAL:	SAN, Plastic Transparent to Check Electrolyte level
SPECIAL FEATURES:	Battery Hold-Downs Fastened to battery top Electrolyte Reservoir in cell cover to avoid electrolyte spillage from inverted battery.

3.1 BATTERY COMPONENTS

Previous experimental cell testing in the First and Second Series of development test cells provided the background data for the selection of the first initial MAR-5013 batteries. Selection of individual cell components is summarized as follows:

3.1.1 Separator

The separator system chosen for the initial MAR-5013 batteries was as follows:

+,pellon, celgard 3400, cellophane, celgard 3400, cellophane, celgard 3400, cellophane, pellon, -

Based upon experimental cell testing at the time of separator selection, the 3 celgard/3 cellophane was the most reliable with respect to cell cycle life.

3.1.2 Zinc Electrode

Based upon experimental cell data, the standard Eagle-Picher zinc electrode with a latex binder was selected. No significant advantages were demonstrated for any of the zinc electrode composition variables.

3.1.3 Nickel Electrode

Nickel electrodes were doubled in the MAR 5013 cell design in order to provide additional AH capacity. Two types of nickel electrodes have been utilized in the RPV program. The two types are described as follows:

Pickett process electrochemical impregnation plates were selected for the First seven (7) MAR-5013 batteries. There were two reasons for the selection of this type nickel electrode. The electrochemical impregnation methods have an advantage over the conventional vacuum impregnated electrode in the areas of dimensional stability and ultimate reduced manufacturing cost.

3.1.3 Nickel Electrode (continued)

Nine (9) batteries were constructed with conventional vacuum impregnated nickel electrodes. Data from the first seven batteries (Pickett), as discussed in in Section 1, Paragraph 3.4, indicated battery capacity was not comparable to batteries or test cells constructed with conventional impregnated vacuum nickel electrodes.

3.2 Cell Design

Table 12 describes the cell characteristics for the first seven (7) MAR-5013 batteries.

TABLE 12
MAR-5013 CELL DESIGN (Pickett)

CONFIGURATION: 8 Double Pos/9 Neg

ELECTRODE SIZE: 2.115" X 4.70"

POSITIVE ACTIVE MATERIAL LOADING: .65 gm/in^2 (single electrode)

TYPE POSITIVE ELECTRODE: Pickett Impregnation on .025" Slurry Sinter

POSITIVE THEORETICAL CAPACITY: 28.3 AH

POSITIVE TAB TO TERMINAL CONNECTION: Spotweld

NEGATIVE ACTIVE MATERIAL LOADING: 1.9 gm/in^2in, no additives

NEGATIVE ELECTRODE THICKNESS: .042"

NEGATIVE ELECTRODE DENSITY: 48 gm/in^3

RATIO NEGATIVE TO POSITIVE THEORETICAL CAPACTIY: 3.33/1

SEPARATOR: Pellon, 3 Celgard/3 Cellophane, Pellon

CELL SURFACE AREA: 150.2 in^2

ELECTROLYTE: 31% KOH, No Additives

3.2 Cell Design (continued)

Table 13 describes the cell characteristics for the conventional MAR-5013 batteries.

TABLE 13

MAR-5013 CELL DESIGN (conventional)

CONFIGURATION: 6 Double Pos-2 Outside Single/7 Neg.

ELECTRODE SIZE; 2.115" X 4.70"

POSITIVE ACTIVE MATERIAL LOADING: .80 gm/in^2
(Single Electrode)

TYPE POSITIVE ELECTRODE: Conventional Impregnation/
Dry Sinter

POSITIVE THEORETICAL CAPACITY: 30.5AH

POSITIVE TAB TO TERMINAL CONNECTION: Spotweld

NEGATIVE ACTIVE MATERIAL LOADING: 1.9 gm/in^2
(no additives)

NEGATIVE ELECTRODE THICKNESS: .042"

NEGATIVE ELECTRODE DENSITY: 48 gm/in^3

RATIO NEGATIVE TO POSITIVE THEORETICAL CAPACITY: 2.70/1

SEPARATOR: Pellon, 3 Celgard/3 Cellophane, Pellon

CELL SURFACE AREA: 131 IN^2

ELECTROLYTE: 31% KOH, No additives

3.3 Manufacture of MAR-5013

A total of sixteen (16) MAR-5013 batteries have been manufactured at the end of this reporting period. All 16 batteries were formed at 150% theoretical capacity at a constant current rate of five (5) amps. Formation discharges were conducted at 14-15 Amps until the first cell in each battery reached a cut-off voltage of 1.35

3.3 Manufacture of MAR-5013 (continued)

volts. Batteries have been constructed for Calendar & Cycle Life Testing, Qualification Testing, and actual Flight Testing.

3.4 Calendar and Cycle Life Batteries

The test objectives for the calendar and cycle life batteries are:

1) Demonstrate calendar life under actual rate of cycling.

2) Optimize the procedure for electrical conditioning.

3.4.1 Calendar and Cycle Life Schedule

The initial calendar and cycle life schedule is as follows:

Battery 1-Receive one cycle per week (indefinite period). The battery will stand in the charged condition and will not be top charged before receiving a 14 amp discharge.

Battery 2-Receive one cycle per week. (indefinite period). The battery will stand in the discharged condition and will receive a routine charge and 14 amp discharge.

Battery 3-(First two tests)

1) The battery will stand in the charged condition for one month and will be top charged before receiving a 45 amp discharge.

2) The battery will stand in the charged condition for 2 months and will be top charged before receiving a 15 amp discharge. Once discharged, the battery will be routinely charged and discharged at 15 amps.

3.4.1.1 Charge-Discharge Method

Routine charging of the Calendar & Cycle Life batteries consisted of a 5 amp constant current charge

3.4.1.1 Charge-Discharge Method (continued)

until battery voltage reached 34.4 volts. Once this voltage was reached, charging was completed by by a 5 amp limited constant potential charge until total AH input during charge was 110% of the previous discharge. Routine discharging of the battery was conducted at 14 amps constant potential initially and later changed to 14 amps constant current when equipment became available.

3.4.1.2 Preliminary Investigations

Preliminary charging investigations, temperature, investigations, and storage performance test were conducted on the MAR-5013 batteries for characterization purposes. Specific results from these tests are presented in the *First Interim Report*. (*Ref.* AFWAL-TR-80-2050).

3.4.2 Testing Status

Cycle status and AH capacity removed for the batteries is summarized in Table 14 on the following page.
At the end of this reporting period, the batteries are eleven (11) months old (activated age).

TABLE 14

MAR-5013 CALENDAR & CYCLE LIFE

AH CAPACITY REMOVED

CYCLE NUMBER	BATTERY 1	BATTERY 2	BATTERY 3
1	19.0	21.1	19.9
2	19.9	21.1	20.1
3	20.9	20.2	19.3
4	19.8	20.0	19.6
5	16.1 (3 weeks)	18.3 (1 week)	unknown
6	15.9 (2 weeks)	6.0 (45 Amps 38°F)	17.5
7	17.5 (1 week)	3.5 (5°F)	18.0
8	16.3 (1 week)	13.5 (45 Amps)	17.7
9	16.8 (1 week)	16.3 (27°F)	19.8
10	14.7 (1 week)	16.3 (2 weeks)	19.1
11	15.6 (1 week)	18.8	18.7
12	14.5 (1 week)	19.8	18.7
13	14.0 (1 week)	18.7	13.5 (1 month) (45 Amps)
14	13.1 (1 week)	17.7	17.5 (2 months (14 Amps)
15	12.1 (1 week)	18.7	*21.0(below 24.3V)
16	14.0 (1 week)	18.7	18.7
17	15.2 (1 week)	15.4 (1 day)	17.6
18	16.1 (1 week)	19.1	19.9
19	12.6 (1 week)	14 (3 days)	18.9
20	11.7 (1 week)	18.0	unknown
21	12.8 (1 week)	19.8	17.0
22	12.1 27.0 volts	19.8	17.6
23	15.5	17.5	15
24	14.5	17.0	18.0

TABLE 14
MAR-5013 CALENDAR & CYCLE LIFE
(continued)

CYCLE NUMBER	BATTERY 1	BATTERY 2	BATTERY 3
25	15.0	18.5	14.8
26	14.3	18.8	16.9
27	13.0	18.6	17.3
28	13.1	18.2	14.8
29	12.3	19.3	17.9
30	13.8	19.5	16.1
31	16.2	unknown	17.8
32	14.2	17.1	
33	12.4	17.2	
34	8.1	16.6	
35	6.8	18.3	
36	9.8	16.0	
37	9.6	15.7	
38	9.9	12.6 (5 days)	
39	10.2	12.9	
40	10.1	13	
41	10.1	14.8	
42	7.25	14.9	
43	14.7	15.6	

Batteries were discharged until the first cell reached 1.35 volts

End-of-discharge voltages remained above 24.3 volts.

3.4.2.1 Battery 1

The battery exhibited capacity fading early in cycle life testing. Testing the condition of one week charged storage between discharges was concluded after cycle 21 because data was not revelant in view of fading battery capacity. Discharges were consistently limited by one cell reaching 1.35 volts early. Voltages for the remaining cells ranged from 1.47-1.51 volts at the end of discharge. Cycling of the battery was continued until cycle #43 when a second cell in the battery reached 1.35 volts.

3.4.2.2 Battery 2

Capacity fading in Battery 2 has no been as dramatic as Battery 1. Battery capacity was maintained in the 19-17 AH range for the first thirty-five cycles; however, it appears to be declining from that point on.

3.4.2.3 Battery 3

Battery capacity also appears to be fading at this point. Figure 4 represents a 45 amp discharge for the battery after a charged stand of one month. The battery was top charged (3 AH input) before discharge. Figure 5 (cycle 14) represents a 15 amp discharge after a charged stand of 2 months. The battery was top charged (4.4 AH input) before discharge. Battery performance was improved during cycle 15 as shown in Figure 5.

3.4.3 Pickett Electrodes

Capacity fading throughout cycle testing has made it undesirable to use Pickett Process nickel electrodes in actual

3.4.3 Pickett Electrodes (continued)

MAR-5013 Flight Batteries and Qualification Cycle Life Batteries. It is not known, at this time, why the capacity fading occurred. Previous investigations in the Development & Evaluation Task demonstrated adequate cycle life without capacity fading in cells containing conventionally impregnated electrodes.

MAR-5013 CALENDAR & CYCLE LIFE
BATTERY 3
45 AMP- DISCHARGE AT 1 MONTH CHARGED STORAGE AT RT
CYCLE 13

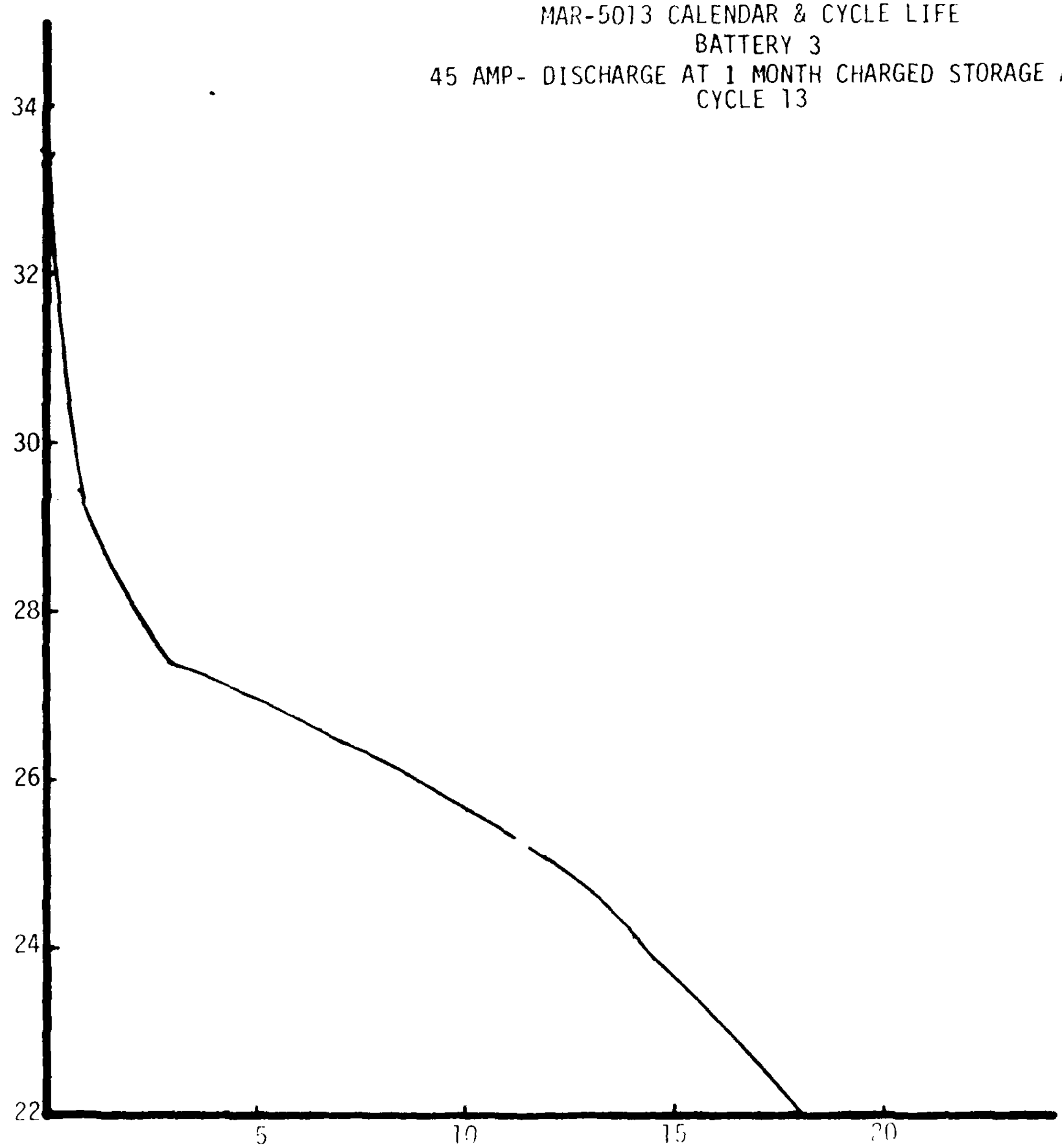


Figure 4.

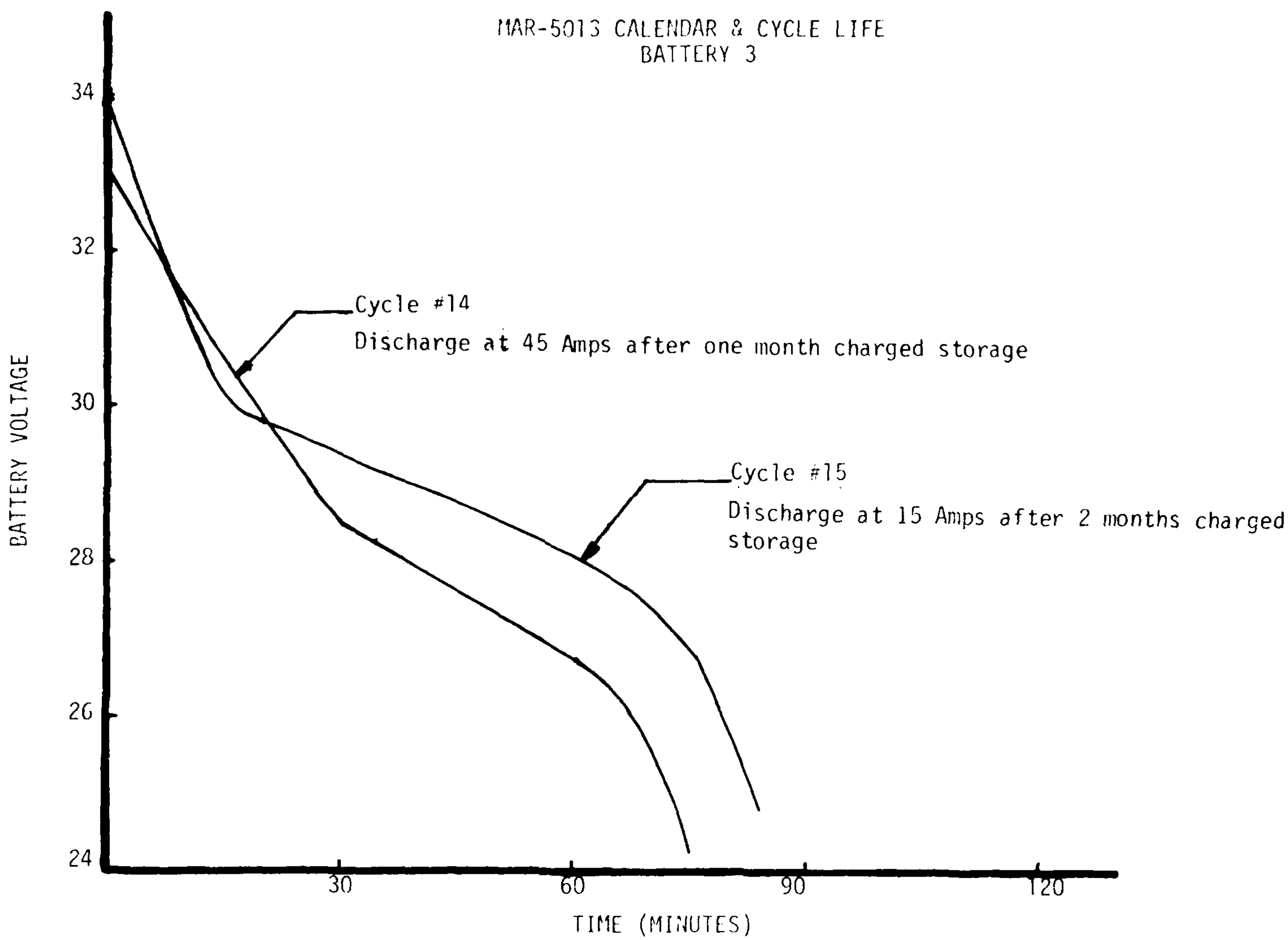

MAR-5013 CALENDAR & CYCLE LIFE
BATTERY 3
BATTERY VOLTAGE
34
32
30
28
26
24
30
60
90
120
TIME (MINUTES)
Cycle #14
Discharge at 45 Amps after one month charged storage
Cycle #15
Discharge at 15 Amps after 2 months charged storage

Figure 5.

3.5 Qualification Batteries

A total of six (6) MAR-5013 batteries have been constructed for qualification testing. The two cycle life batteries were constructed with conventionally impregnated nickel electrodes. the remaining four (4) batteries contain Pickett nickel electrodes. The qualification test matrix and battery test status is summarized in Table 15 on the following page.

TABLE 15

MAR-5013 QUALIFICATION TESTING REQUIREMENT

NON OPERATING TEST		TEST SPECIMEN NUMBER					
		1	2	3	4	5	6
Humidity	Procedure II, Method 507 MIL-STD-810			$\boxed{X}$			
Temperature Shock	Procedure I, Method 503	$\boxed{X}$					
Sand & Dust	Procedure I, Method 510 MIL-STD-810			$\boxed{X}$			
Salt Fog	Procedure I, Method 509 MIL-STD-810						$\boxed{X}$
Fungus	Procedure I, Method 508.1 MIL-STD-810						X
OPERATING TEST							
Mechanical Shock	Procedure I, Method 516 MIL-STD-810. The shock test shall be a half sine wave with a 15g peak and a duration of .011 seconds.	$\boxed{X}$					
Vibration	Battery shall perform normally during vibration of 10 to 500 Hz with input of .036 inch double amplitude or 10g whichever is the limiting factor. Vibration shall be applied in the normal upright position for 30 minutes.	$\boxed{X}$	$\boxed{X}$				$\boxed{X}$
Attitude	Battery discharge performance shall not be affected by an angle of 60^o minimum from either horizontal axis.	$\boxed{X}$	$\boxed{X}$				
Altitude	Battery discharge shall not be affected by operation at altitudes up to 60,000 ft., and climb to or dive from this altitude in a period of 15 minutes.	$\boxed{X}$					
Acceleration	The battery shall perform normally during accelerations of 7.5g along the +X,-X,+Y, -Y, and +Z axis for 1.0 sec.	$\boxed{X}$					

TABLE 15 (continued)

MAR-5013 QUALIFICATION TESTING	REQUIREMENT	TEST SPECIMEN NUMBER 1	2	3	4	5	6
Cycle Life, 15A	The battery shall achieve TBD cycles when cycled at a 15 amp rate of discharge to an 80% depth of discharge. Battery voltage shall be 24.3 volts or greater at end of discharge.				X		
Cycle Life, 45A	The battery shall achieve 50 cycles when cycled at a 45 amp rate of discharge to a 50% depth of discharge. Battery voltage shall be 24.3 volts or greater at end of discharge.					X	

$\boxed{X}$ indicates testing complete

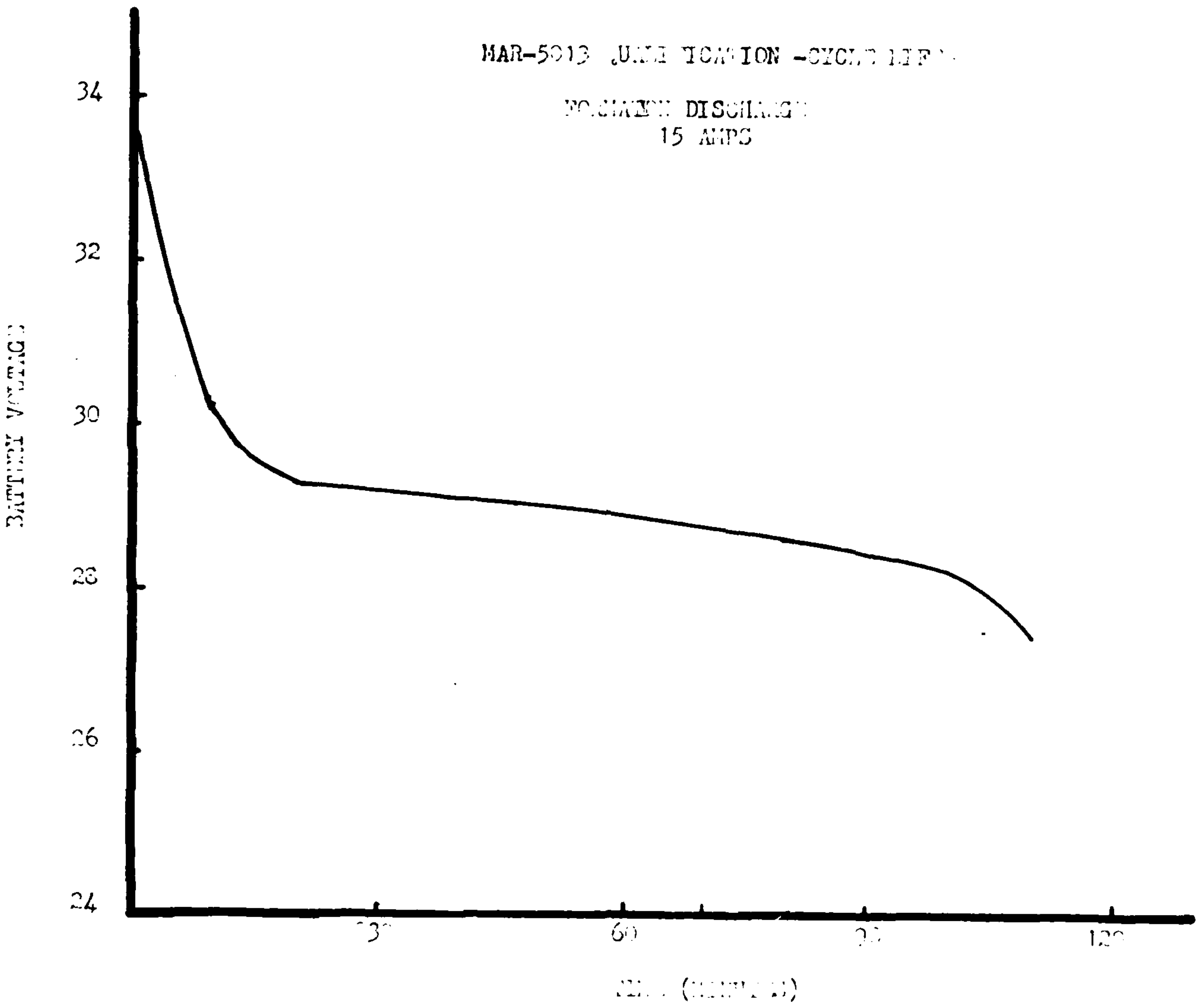
(X) indicates testing in progress

3.5.1 MAR-5013 Qualification Cycle Life

Two (2) qualification cycle life batteries and seven (7) flight test batteries were constructed and activated. All batteries contained conventionally impregnated nickel electrodes, rather than the electrochemically impregnated Pickett electrodes. Capacity fading observed in batteries with Pickett electrodes made it undesirable to continue using this type electrode. The batteries were formed at 5 amps constant current. Figure 6 represents a typical 15 amp formation discharge for the conventional batteries. Discharge was concluded when the first cell in each battery reached a cut-off voltage of 1.35 volts. Test status for the two (2) qualification cycle life batteries is described as follows:

3.5.1.1 15 Amp Cycle Life (Test Specimen 4)

The battery has completed thirty-five (35) cycles at the conclusion of this reporting period. Discharges 16, 24, and 35 are shown in Figure 7.



6

MAR-5013 QUALIFICATION CYCLE LIFE
15 AMP RATE
80% DOD

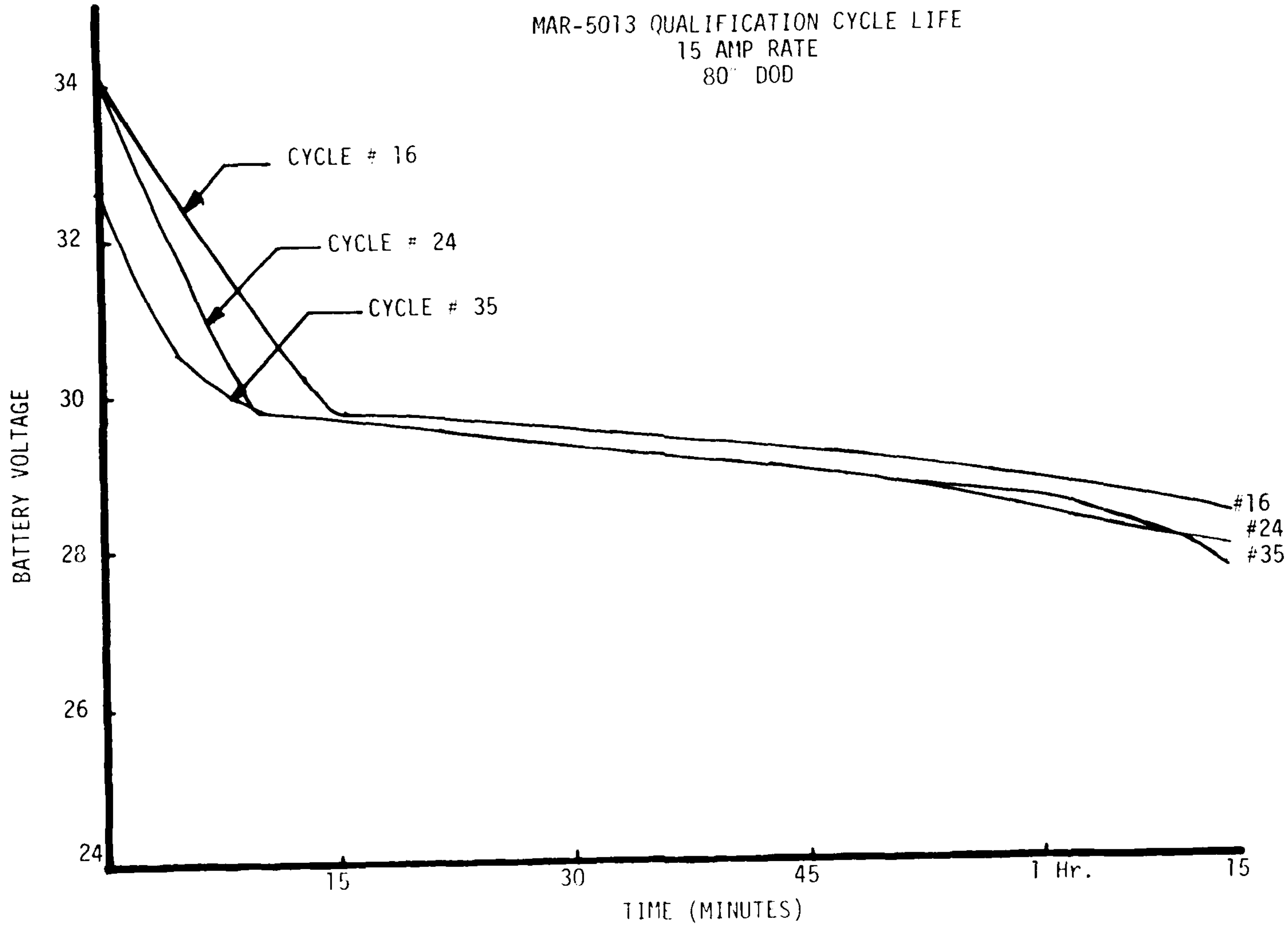


Figure 7

3.5.1.2 45 Amp Cycle Life (Test Specimen 5)

The battery has completed twenty-seven (27) cycles at the conclusion of this reporting period. Discharges 8, 18, and 27 are shown in Figure 8.

3.5.2 Fungus Testing (Test Specimen 6)

Fungus testing for the MAR-5013 will be conducted at the same time it is conducted for the MAR-5011. Fungus testing has to be contracted outside EP facilities.

MAR-5013 QUALIFICATION-CYCLE LIFE
45 AMP
50 DOD

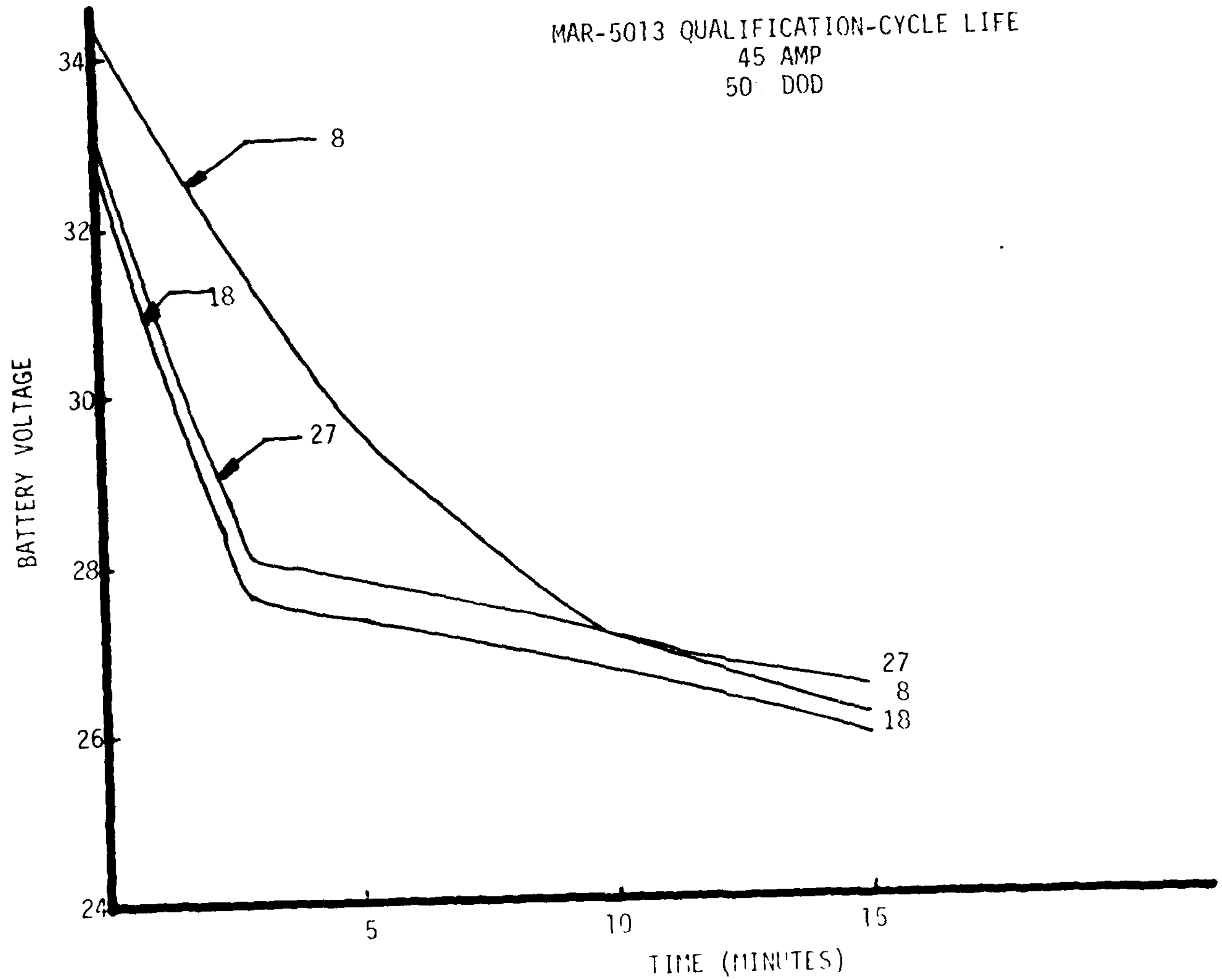


FIGURE 8

3.6 MAR-5013 Flight Batteries

Seven (7) MAR-5013 Flight Test batteries, have been constructed and shipped to Tyndall AFB for testing in the BQM-34A remotely piloted target drone. The first five (5) batteries were shipped activated, and the remaining two (2) batteries were shipped in the unactivated condition. Activation methods and formation methods are discussed as follows:

3.6.1 Activation

Activation of the MAR-5013 battery was accomplished manually. At the end of activation, the electrolyte level was between the top of the plates and the top of the separation. Cell electrolyte quantities for each battery are listed in Table 16.

The cell electrolyte quantity was decreased because of foaming problems encountered during the formation cycle on batteries with 80 cc of electrolyte per cell. Foaming resulted from the surfactant wetting agent in the Celgard 3400. With decreased electrolyte levels, foaming problems were not encountered. The electrolyte level in cells activated with 70 cc of electrolyte was still between the top of the plates and the top of the separation.

3.6.2 Battery Formation

The five batteries, activated at Eagle-Picher, were formed at a 5 Amp constant current rate. Amp-hour input was 150% of theoretical capacity. The batteries were discharged at a 15 amp rate. Discharge Amp Hour capacities

3.6.2 Battery Formation (continued)

for the seven batteries are listed in Table 16. Additional cycles were placed on Batteries 4 & 5 before shipment to Tyndall in order to improve AH capacity.

3.6.3 Battery Status

Approximately six (6) weeks into flight testing,the flight batteries were returned to Eagle-Picher for conditioning.The seventh battery was lost on a flight mission when the target drone was shot down. Refer to Table 16 for a summary of battery history prior to return to Eagle-Picher. Battery performance difficulties encountered at Tyndall were mainly caused by a combination of inadequate electrolyte volume and charging methods which caused cells to become out-of-balance and reach high voltages. Originally, the batteries were activated with a reduced amount of electrolyte in order to help reduce the foaming problems encountered with the electrolyte interacting with the separator wetting agent. The electrolyte level was further reduced by charging methods at Tyndall. The batteries were charged, at least part of the time, without vent plugs which allowed for a reduction in electrolyte. Also, in some instances, the batteries were overcharged, which resulted in electrolyte (water) loss and further cell voltage imbalances.

TABLE 16

MAR-5013 FLIGHT BATTERIES STATUS

SPECIMEN NO.	FORMATION CHARGE	FORMATION DISCHARGES 15 Amp Constant Current	RECHARGES	TOP CHARGE	LOAD CHECKS 20 Amp 5 Min	CAPACITY CHECK (15 Amp) Discharge 12.5 AH Min.	FLIGHT MISSION
1	At E-P 80 cc Electrolyte per cell	#1 23.8 AH	2	5	2	2	1
2	At E-P 80 cc Electrolyte per cell	#1 30 AH	4	2	1	4 Failed to meet last check	4 Went in gulf with drone
3	At E-P 80 cc Electrolyte per cell	#1 29.5 AH	1	1	0	Acceptable before de- stroyed in flight	1 Lost Battery drone shot down
4	At E-P 75 cc Electrolyte per cell	#1 23 AH #2 28.3 AH	4	4	1	5 Failed to meet last check	1
5	At E-P 70 cc Electrolyte per cell	#1 22.5 AH #2 24.1 AH #3 27.3 AH	5	2	1	6 Failed to meet last 2 checks	0 Bench Battery
6	Shipped Dry 70 cc Electrolyte per cell at Tyndall	#1 26.25 AH At Tyndall	1	4	Invalid	2	0
7	Shipped Dry 70 cc Electrolyte per cell at Tyndall	#1 Data Not Known	4	0	0	Met Standard Until de- stroyed in shop	0

3.6.4 Battery Conditioning

The reconditioning procedure five (5) flight batteries were subjected to is described as follows:

1. Record open circuit voltages.
2. Add electrolyte until the level is at the top of the separation.
3. Low rate 3 amp constant resistance discharge to a cut-off voltage of 0.3 volts per cell.
4. 3.0 amp constant current charge.
5. Low rate 3.0 amp constant resistance discharge until the first cell reaches 1.35 volts.
6. Three additional cycles:
   - A. Charge: 3.0 amps constant current
   - B. Discharge: 15.0 amp constant resistance discharge until the one cell reaches 1.35 volts.

3.6.4.1 Battery Inspection

The Flight Batteries were examined as received from Tyndall for evidence of damage. All six (6) batteries appeared extremely dry. There was no evidence of free electrolyte. Battery 2 went in the gulf when the drone was shot down. Examination of the battery indicated approximately two inches of salt water had stood in the drone battery box. The top of the battery showed signs of corrosions near the center cells around the terminal area. Examination of battery 7 indicates this battery may have received

3.6.4.1 Battery Inspection (continued)

an extremely deep discharge which generated internal cell heat and resulted in cell swelling. The battery was not reconditioned.

3.6.4.2 Battery Conditioning Results

The capacity performance of the batteries while at Eagle-Picher is summarized below. All discharges are constant resistance discharges. Refer to Table 17 for conditioning results per 3.6.4.

TABLE 17

FLIGHT BATTERY CAPACITY PERFORMANCE

BATTERY NO.	Open Circuit Voltage Range	3 Amp 0.3 v/cell Cut-off	3 Amp 1.35 v/cell Cut-off	15 Amp 1.35 v/cell Cut-off	15 Amp 1.35 v/cell Cut-off	15 Amp 1.35 v/cell Cut/off
1	1.74-1.75	27	26	26	27	27
2	All 1.73	21	26	24	27	25
4	All 1.74	32	28	28	28	27
5	1.72-1.73	23	27	27	26	26
6	All 1.71	14	29	26	26	28

Battery performance at the end of the conditioning procedure exceeded the 12.5 AH service capacity requirement. At this point the batteries were shipped back to Tyndall AFB.

3.6.5 Further Testing

Further testing of the batteries at Tyndall has been accomplished with a modified charging procedure that is more compatible to the available charging

3.6.5 Further Testing (continued)

equipment at Tyndall. Batteries are now charged at 3 amps constant current until battery voltage reaches 34.4 volts. Battery charging has been successful at Tyndall using this method. Activation procedures have also been revised. Changes in activation procedures are reflected in Paragraph 4.2.1 dealing with activation of the MAR-5011 Qualification Batteries. Changes in activation procedures are also reflected in the MAR-5013 Operation Manual. Presently, the Flight Batteries have completed ground testing at Tyndall and are now being routinely flown in flight missions.

SECTION II

MAR-5011

1.0 INTRODUCTION

The objective of this portion of the program is to develop the technology necessary for a long-life, low cost, rechargeable nickel-zinc battery as a replacement for existing lead-acid batteries used in PQM-102 target drones. The nickel-zinc batteries herein described (Eagle-Picher Part No. MAR-5011) potentially have a wider range of applications than the more specialized MAR-5013 battery. The MAR-5011 nickel-zinc batteries are to be physically and electrically interchangeable with the existing lead-acid batteries. The current lead-acid battery is 18 Amp-Hours constructed in a 22 Amp-Hour nickel cadmium battery box.

The general technical requirements for the nickel-zinc battery are:

1) Battery voltage shall be compatible to the vehicle electrical system (24 volt nominal).
2) Battery charging requirements compatible to existing ground charging equipment.
3) Battery weight for the filled, complete, flight ready battery shall not exceed 56 pounds.
4) Battery cycle life shall exceed 120 cycles.
5) Battery operation shall be able to be conducted in a temperature range of $0^{o}F$ to $165^{o}F$.

2.0 BATTERY DESIGN

The nickel-zinc battery to potentially be used for the PQM-102 target drone has been assigned Eagle-Picher battery Number MAR-5011. The general characteristics of this battery are listed in Table 18.

TABLE 18

MAR-5011 BATTERY DESIGN

NUMBER OF CELLS: 15

BATTERY WEIGHT: 50 lbs.

SIZE: 7.66" X 9.96" X 8.75"

NOMINAL VOLTAGE: 24V

OPEN CIRCUIT VOLTAGE, CHARGED: 26.5 - 28V

OPEN CIRCUIT VOLTAGE, DISCHARGED: 24.5 - 26V

SPECIFICATION OPEN CIRCUIT VOLTAGE: 26 - 28V

CELL CASE MATERIAL: SAN

ELECTROLYTE LEVEL: TILT BATTERY 90^{o} & OBSERVE LIQUID LEVEL THROUGH TRANSPARENT COVER.

3.0 CELL DESIGN

The MAR-5011 individual cell characteristics are listed in Table 19 and Table 20 respectively. Table 19 lists cell characteristics for cells containing Pickett process nickel electrodes. Table 20 lists cell characteristics for cells containing conventionally impregnated nickel electrodes.

TABLE 19

MAR-5011 CELL DESIGN

(PICKETT)

CONFIGURATION: 14 SINGLE POS/15 NEG

ELECTRODE SIZE: 6.30" X 2.96"

POSITIVE ACTIVE MATERIAL LOADING: .65 GM/IN^2

TYPE POSITIVE ELECTRODE: PICKETT IMPREGNATION ON .025" SLURRY SINTER

POSITIVE THEORETICAL CAPACITY: 46.4 AH

POSITIVE TAB TO TERMINAL CONNECTION: BOLTED

NEGATIVE ACTIVE MATERIAL LOADING: 1.0 GM/IN^2, NO ADDITIVES

NEGATIVE ELECTRODE THICKNESS: .023"

NEGATIVE ELECTRODE DENSITY: 45 GM/IN^3

RATIO NEGATIVE TO POSITIVE THEORETICAL CAPACITY: 3.53/1

SEPARATOR: PELLON, 3 CELGARD/3 CELLOPHANE, PELLON

CELL SURFACE AREA: 493 IN^2

ELECTROLYTE: 31% KOH, NO ADDITIVES

TABLE 20

MAR-5011 CELL DESIGN (conventional)

CONFIGURATION: 13 SINGLE POS/14 NEG

ELECTRODE SIZE: 6.30" X 2.96"

POSITIVE ACTIVE MATERIAL LOADING: .80 GM/IN^2

TYPE POSITIVE ELECTRODE: CONVENTIONAL IMPREGNATION DRY SINTER

POSITIVE THEORETICAL CAPACITY: 53.1 AH

POSITIVE TAB TO TERMINAL CONNECTION: BOLTED

NEGATIVE ACTIVE MATERIAL LOADING: 1.0 GM/IN^2, NO ADDITIVES

NEGATIVE ELECTRODE THICKNESS: .023"

NEGATIVE ELECTRODE DENSITY: 45 GM/IN^3

RATIO NEGATIVE TO POSITIVE THEORETICAL CAPACITY: 2.84/1

SEPARATOR: PELLON, 3 CELGARD/CELLOPHANE, PELLON

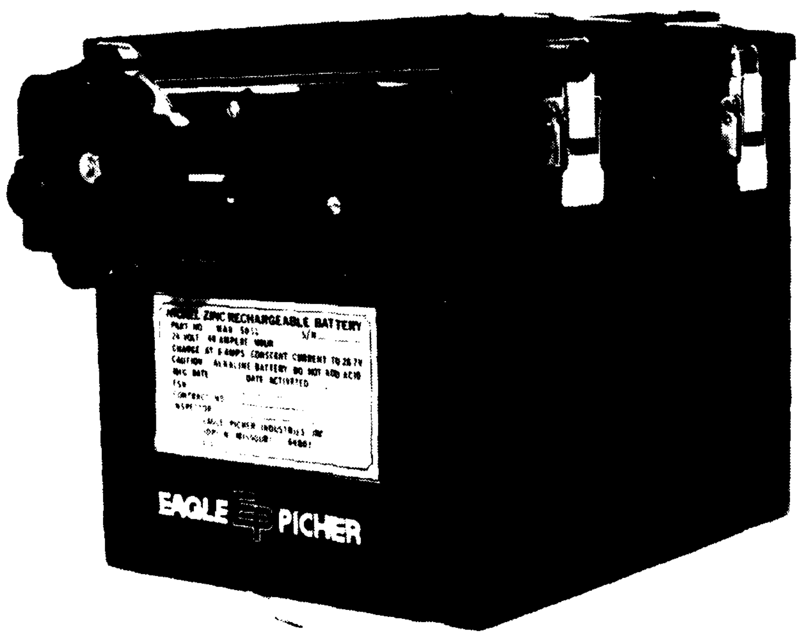
CELL SURFACE AREA: 458 IN^2

ELECTROLYTE: 31% KOH, NO ADDITIVES

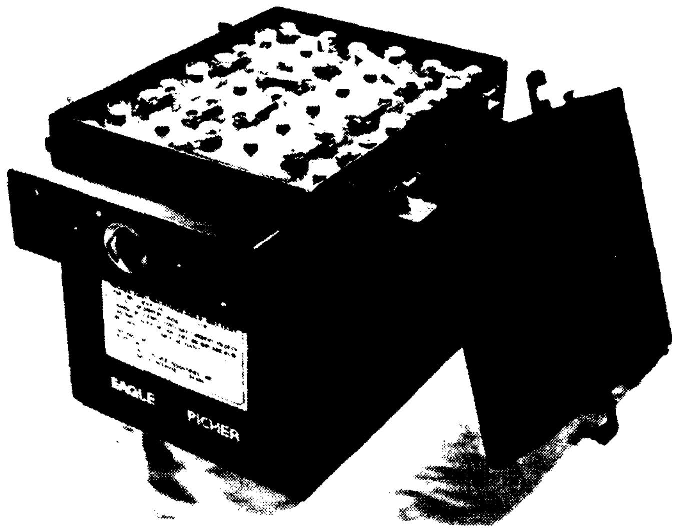
The MAR-5011 battery has single positive plates. The single plate configuration was selected instead of double plates, as in the MAR-5013, because the MAR-5011 battery has a wider range of applications and could possible operate at lower temperatures than the MAR-5013.

4.0 MANUFACTURE OF MAR-5011

Six (6) MAR-5013 batteries have been constructed and manufactured during this interim reporting period. Three batteries were designated for Calendar & Cycle Life testing, and three batteries were designated for Qualification testing. Figure 9 is a picture of a MAR-5011 battery. Figure 10 shows the MAR-5011 battery with the cover removed. Figure 11 shows a MAR-5011 cell.

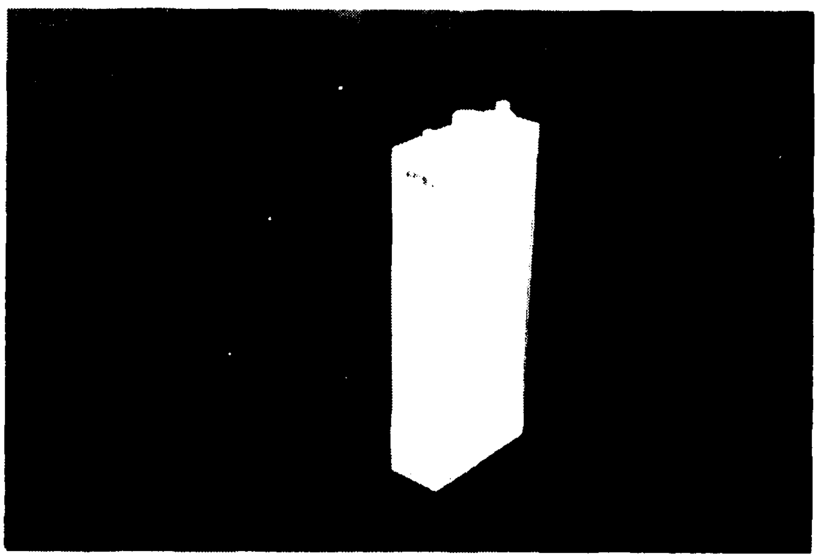


MAR-5011 BATTERY
FIGURE 9.



MAR-5011 BATTERY COVER REMOVED

FIGURE 10



MAR-5011 CELL

FIGURE 11

4.1 Mar-5011 Calendar & Cycle Life Batteries

Three (3) MAR-5011 batteries were constructed for Calendar & Cycle Life Testing. Batteries were constructed with Pickett nickel electrodes before capacity fading in the MAR-5013's became evident. Routine charging of the Calendar & Cycle Life Batteries consisted of an 8 Amp constant current charge until battery voltage reached 28.7 volts. Once this voltage was reached, charging was completed by an 8 amp limited constant potential charge until total AH input was 110% of the previous discharge. Routine discharging was initially conducted at 19.1 Amps constant current, but later changed to 26 amps constant resistance. Battery discharge was concluded when the first cell in the battery reached 1.35 volts.

4.1.1 Testing Status

Cycle status and AH capacity removed for the batteries is summarized in Table 21. At the end of this reporting period, the batteries had an activated age of seven (7) months.

TABLE 21

MAR-5011 CALENDAR & CYCLE LIFE

AH CAPACITY REMOVED

CYCLE NUMBER	BATTERY 1	BATTERY 2	BATTERY 3
1	29.8	32.4	32.7
2	34.0	33.7	33.7
3	34.9	33.3	35.9
4	34.3	30.8	25.4
5	34.6	34.0	27.3
6	*17.1	34.1	33.3
7	*17.1	unknown	32.4
8	*16.8	8(34°F 80 amps)	34.9
9	*17.1	unknown	32.4
10	*17.1	29.7	31.8
11	35.6	26.2	30.8
12	32.3	32.3	31.8
13	32.6	30.3	31.4
14	33.6	11(discharge inter-upted	31.4
15	34.8	28.6	31.8
16	32.9	30.5	29.2
17	30.3	27.2	31.4
18	29.7	36 immediately after charge	31.8
19	50.6 (conditioning)	33.0	33.4
20	29.9		33.2
21	29.3		32.3
22	29.0		31.1
23	32.3		20
24	30.5		29.1

TABLE 21 (continued)

MAR-5011 CALENDAR & CYCLE LIFE

CYCLE NUMBER	BATTERY 1	BATTERY 2	BATTERY 3
25	28.8		29.1
26	30.2		30.9
27	30.3		24.0
28	26.3		15.7
29			24.0
30			18.4
31			25.9
32			27.2
33			

* Intentional 50% capacity discharge to determine if subsequent discharge performance would be affected.AH capacity was not affected in Cycle 11.

4.1.2 Testing Results

Battery performance has never been satisfactory for the batteries with Pickett type electrodes. A low rate, deep discahrge on Battery 1 (Cycle #19) did not improve subsequent discharges.

4.2 MAR-5011 Qualification Batteries

Three of the six MAR-5011 Qualification Batteries were constructed during this reporting period. Special battery characteristics are listed in Table 22.

TABLE 22

MAR-5011 QUALIFICATION BATTERIES

TEST SPECIMEN NUMBER	POSITIVE CONFIGURATION	NEGATIVE GRID MATERIAL
* 1	Pickett	Silver
2	Pickett	Copper
3	Pickett	Copper
* 4	Conventional	Silver
* 5	Conventional	Silver
6	Conventional	Copper

* Constructed during this reporting period. Copper grid material was incorporated in the batteries because data did not indicate copper grid affected battery performance in the Third Series Test Cells.

The enviromental Qualification test matrix the batteries are to be subjected to is outlined in Table 23.

TABLE 23

MAR-5011 QUALIFICATION TESTING

REQUIREMENT

		TEST SPECIMEN NUMBER					
		1	2	3	4	5	6
NON-OPERATING TEST							
Humidity	Procedure II, Method 507 MIL-STD-810			X			
Temperature Shock	Procedure I, Method 503	X					
Sand & Dust	Procedure I, Method 519 MIL-STD-810				X		
Salt Fog	Procedure I, Method 509, MIL-STD-810					X	
Fungus	Procedure I, Method 508.1 MIL-STD-810	X					
OPERATING TESTS							
Mechanical Shock	Procedure I, Method 516 MIL-STD-810. The shock test shall be a half sine wave with a 15g peak and a duration of .011 seconds.	X					
Vibration	Battery shall perform normnally during vibration of 10 to 500 Hz with input of .036 inch double amplitude or 10g whichever is the limiting factor. Vibration shall be applied in the normal upright position for 30 minutes.		X				
Attitude	Battery discharge performance shall not be affected by an angle of 60° minimum from either horizontal axis.		X				
Altitude	Battery discharge shall not be affected by operation at altitudes up to 60,000 ft., and climb to or dive from this altitude in a period of 15 minutes.	X					

TABLE 23. (continued)

MAR-5011 QUALIFICATION TESTING

OPERATING TESTS (continued)	REQUIREMENT	TEST SPECIMEN NUMBER 1	2	3	4	5	6
Acceleration	The battery shall perform normally during accelerations of 7.5g along the +Y,-Y,+Y, -Y, and +Z axis for 1.0 sec.		X				
Low Temperature	The battery shall be discharged at temperatures of 30°F, 0°F, -10°F, and -20°F to determine the effect of temperature on battery capacity			X	X		
High Temperature	The battery shall be discharged at temperatures of 120°F, 140°F, and 160°F to determine the effect of temperature on battery capacity.			X	X		
Cycle Life	The battery shall be cycled at a two (2) hour rate of discharge to an 80% DOD until the battery will no longer deliver 80% of rated capacity above 20.2 volts.					X	

4.2.1 Battery Activation

The MAR-5011 Qualification Batteries were the first batteries to be activated since the MAR-5013 Flight Batteries. The MAR-5011 batteries were manually activated and allowed to soak 72 hours prior to charging. During this soak period, the electrolyte was maintained over the top of the separation instead of between the top of the plates and the top of the separation as in the MAR-5013 Flight batteries. This elevated electrolyte level insures a properly "wet" cell before charging, and also helped to reduce the foaming problems encountered with the MAR-5013 Flight batteries. The wetting agent of Celgard 3400 separation is a surfactant. Battery activation with elevated electrolyte levels made it possible to remove more of the surfactant and reduce foaming. The MAR-5011 Qualification Batteries did not exhibit signs of foaming during formation. The final electrolyte level was adjusted between the top of the plates and the top of the separation during the formation charge.

4.2.2 Battery Formation & Testing Status

Battery formation was conducted at 8 Amps constant current. Capacity input was 150% of theoretical capacity. The batteries were discharged at 26 amps constant resistance. At the conclusion of this reporting period, the batteries have two cycles on them. Discharge capacities for the first two (2) cycles are listed in Table 24.

TABLE 24

MAR-5011 QUALIFICATION BATTERIES-DISCHARGE CAPACITIES

TEST SPECIMEN NUMBER	AH CAPACITY REMOVED	
	Discharge 1	Discharge 2
1	28.9	30.8
3	46.6	48.5
5	51.8	48.1

As indicated by the table, a dramatic difference in battery capacity performance is seen between batteries containing Pickett positive electrodes and batteries containing conventional positive electrodes.

SECTION III

SUMMARY AND CONCLUSIONS

Two nickel-zinc RPV batteries, the MAR-5013 and the MAR-5011, are currently being developed that offer respective viable alternatives to the standard RPV batteries presently in service on the BQM-34A and the PQM-102. The MAR-5013 has basically the same configuration and weight as the existing BQM-34A lead-acid battery, but is rated at 22.5 Ampere-Hours vs. 12.5 Ampere-Hours for the lead-acid battery. The MAR-5011 has the same configuration as the existing PQM-102 lead-acid battery, but weighs 50 pounds vs. 56 pounds for the lead acid battery. Additionally, the MAR-5011 battery is rated a 40 Ampere-Hours vs. 18 Ampere-Hours for the lead acid battery. Currently, on the PQM-102, two lead-acid batteries are paralleled to increase battery capacity to 36 Ampere-Hours. By using one MAR-5011, it would be possible to reduce RPV weight by 56 pounds and still have sufficient battery capacity to perform the required missions.

Work effort during the next reporting period will primarily concentrate on completing Qualification Testing for both type batteries as well as completing remaining battery construction. A total of thirty-four batteries will be constructed during the next reporting period: 8 MAR-5013 Flight Batteries; 3 MAR-5011 Qualification Batteries; 15 MAR-5011 Flight Batteries; and 8 MAR-5011 size "Special Separation" Batteries. All Flight Batteries will incorporate conventionally vacuum impregnated nickel electrodes. The 8 MAR-5011 size "Special Separation" Batteries will be tested at Wright-Patterson Air Force Base and will incorporate nickel coated Celgard separation for testing and evaluation purposes.

DATE

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